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(6) A PRELIMINARY ANALYSIS OF SPACE BLAST.

by

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Many people feel there is no blast capability of a weapon in the space environment of a vacuum. The purpose of this report is to clarify the thinking on this point, and to show that an explosive weapon operating in a vacuum would produce extensive damage due to blast-like effects. It is true that in a vacuum there will be no shock or air blast as would be experienced by a detonation of an explosive charge in air. But what happens is that the near-field effects zone, which is the zone directly affected by the explosion products, extends to infinity and all of the energy and momentum of the explosive remains in the products of the explosives until a target is encountered.

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FOREWORD

The results of two case studies examining the blast capability of a weapon in the space environment of a vacuum are investigated. Comparison of computed blast parameters in a vacuum to those produced by the same weight charge at the same distances in air are also discussed.

This work was undertaken as part of a continuing effort to strengthen our capabilities in support of blast studies. The tests were performed during fiscal year 1978 and funded by Navy Director of Laboratory Programs Task Assignment ZR000-01-01.

This report on preliminary findings of the study is released at the working level and is subject to modification. It should not be used as authority for action.

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2 October 1978

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INTRODUCTION

Recently, it has come to our attention that many people feel there is no blast capability of a weapon in the space environment of a vacuum. The purpose of this report is to clarify the thinking on this point, and to show that an explosive weapon operating in a vacuum would produce extensive damage due to blast-like effects. It is true that in a vacuum there will be no shock or air blast as would be experienced by a detonation of an explosive charge in air. But what happens is that the near-field effects zone, which is the zone directly affected by the explosion products, extends to infinity and all of the energy and momentum of the explosive remains in the products of the explosives until a target is encountered.

ASSUMPTIONS

In order to examine the above stated situation, a short analysis was undertaken to show the effects that could be expected if an explosive charge was fired in vacuum against a target. The assumptions made were that the expansion of the products is like an expanding universe in which there is a linear velocity gradient from the outside of the product cloud, which is moving at the highest velocity, going to zero at the center. This is essentially a time-varying uniform density spherical expansion.

DERIVATION OF EQUATIONS

Having made the above assumptions, we will examine two cases.

Case No. 1. We assume that the velocity of the explosive charge relative to the target is zero, and then we further assume that there are elastic collisions of the gas with the target, but no gas-gas collisions. In this case, the amount of momentum imparted to the target by each gas particle would be twice the amount of momentum carried by the particles. The reflected pressure would then depend on the amount of momentum delivered per unit area per unit time. With this assumption we can write some equations related to our assumptions. The reflected pressure which is equal to the time rate of change per momentum per unit area is the derivative of mV/dt, i.e.,

$$P_r = \frac{d(mV)}{Adt} = \frac{dI_r}{dt}$$

The reflected pressure is equal to twice the density times the velocity of the material reaching the target point at that time. The density is time-varying and can be expressed in terms of the initial density, ρ_o, the initial radius of the explosive charge, r_o, the maximum velocity, V_m, the time, t, and the distance to the target, r; i.e.,

$$P_r = 2(\rho_o(\frac{r_o}{r_o + V_m t})^3)(V_m(\frac{r}{r_o + V_m t}))^2$$

There are other terms of interest. One is the time required to reach the target, t_o, and which is equal to the radius to the target minus the initial radius of the explosive charge divided by the maximum velocity; i.e.,

$$t_o = \frac{r-r_o}{V_m}$$

Another term is the time after first encounter, t', which is equal to the actual time minus the time required for the first encounter with the target; i.e., $t' = t - t_o$.

We can integrate the pressure as a function of time to get the impulse, producing a closed form solution; i.e.,

$$I_r = 1/2\ V_m\ \rho_o\ r^3[\frac{1}{r^2} - \frac{r^2}{(r + V_m\ t')^4}]$$

Case No. 2. This case covers the interaction of the product cloud with the target when there are relative velocities between the target and the explosive charge. Examine Figure 1 to see the terms that will enter into this calculation. The target is moving toward the warhead at a closing velocity, V_c; this is assumed to be the anti-parallel closing velocity. If the target continued on this path it would pass by the explosive charge at a distance which would be the miss radius, r_m. It is further assumed that an influence fuze is used to set a range, r_f, at which detonation will occur. As the target continues to approach, it would move along the anti-parallel line a distance equal to the closing velocity, times the time it takes to reach the explosion products. The products expanding from the explosive charge would travel a distance equal to the maximum velocity, times the time it takes to reach the target. From the geometry, we can determine the relationships between these terms to get the value of the time it takes to reach the target. The angle ϕ is equal to the arc sine of the miss distance over the fuzing range; i.e.,

$$\phi = \sin^{-1} \frac{r_m}{r_f}$$

5

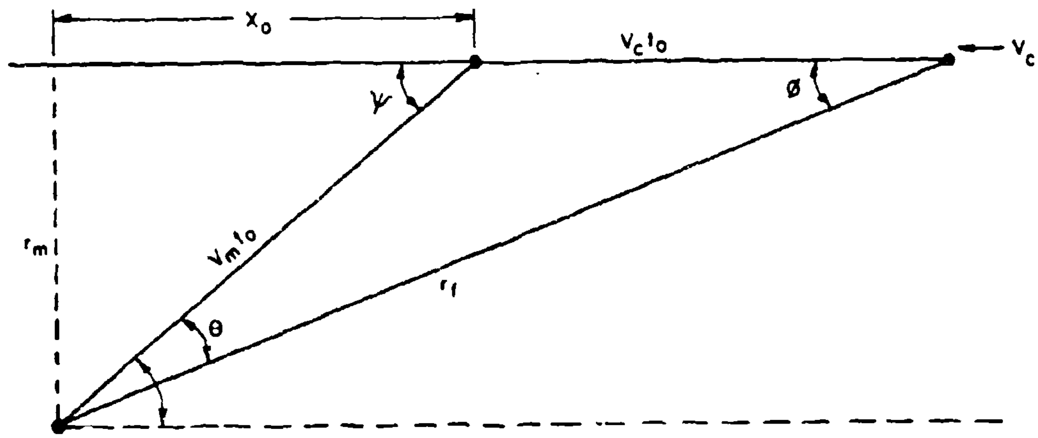

FIGURE 1. Geometry of Case No. 2 Encounter

The angle θ is equal to the arc sine of the closing velocity divided by maximum velocity, times the miss distance divided by the fuzing range, i.e.,

$$\theta = \sin^{-1}\left(\frac{V_c}{V_m}\frac{r_m}{r_f}\right)$$

Adding these two angles together gives us the angle Ψ, i.e., $\Psi = \phi + \theta$. The time to reach the target is equal to the miss distance divided by the maximum velocity times the sine of Ψ. The time of interaction in the gas cloud with the target is equal to the actual time minus the time to reach the target; i.e., $t' = t - t_o$. The gas velocity, V_g, is a vector quantity, the magnitude is

$$V_g = \frac{V_m\ r}{R_o + V_m\ t'}$$

The direction of the gas velocity encountering the target varies with time (Figure 2). The gas velocity is added vectorially to the relative closing velocity to get the relative velocity of the gas products and the relative approach angle. The reflected pressure is then twice the density of the products, times the relative velocity squared; i.e.,

$$P_r = 2\rho_o\left(\frac{r_o}{R_o + V_m\ t'}\right)^3 V_r^2$$

The integration to determine the reflected impulse was done by simple trapezoidal integration of the reflected pressures determined at different times following the initial interaction.

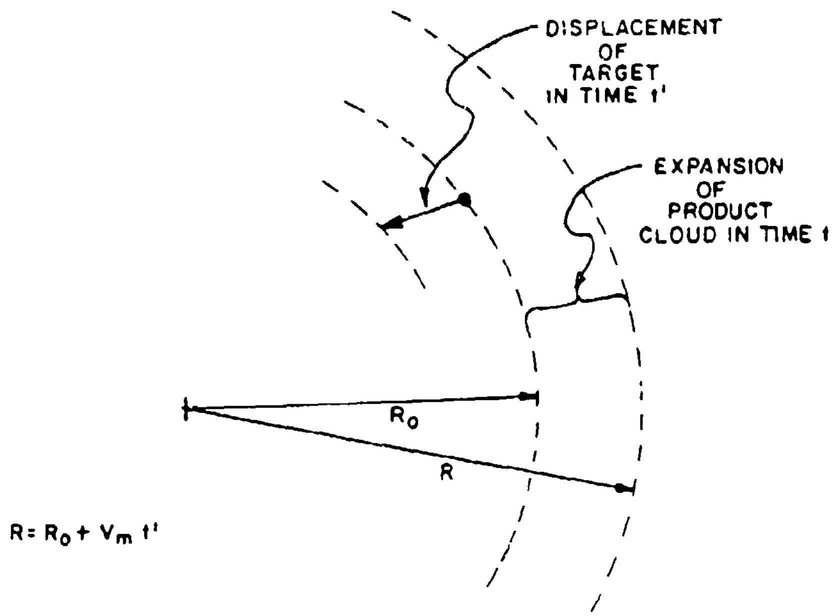

FIGURE 2. Product Cloud Expansion and Target Motion for Case No. 2 Encounter.

RESULTS

Results of typical examples for case studies 1 and 2 are shown in the tables. Table 1 shows the results for an explosive charge one-tenth meter in initial radius, with the density of the explosive 1,700 kilograms per cubic meter, and the maximum velocity chosen being 10 kilometers per second. Calculations were run for a radius to the target of 1 meter, 2 meters, and 5 meters.

In Case No. 2, again the initial radius of the explosive was one-tenth meter in initial radius, the density of the explosive 1,700 kilograms per cubic meter, and a maximum velocity of 10 kilometers per second. The reflected pressure and the approximate reflected impulse as a function of time after initial interaction are shown in Table 2.

In the last case, where the miss distance is 5 meters, the target moves out of the cloud just after 2 milliseconds, so that no further interaction with the cloud occurs. This occurs because the closing velocity is 15 kilometers per second while the maximum gas velocity is 10 kilometers per second. The values shown for reflected pressure are in bars, and the reflected impulse is in bar milliseconds.

TABLE 1. Results of Explosive Charge in Case No. 1.

r_o = 0.1 m, ρ_o = 1,700 kg/m^3, V_m = 10 km/sec						
t' (msec)	t_o = 0.09 msec, r = 1		t_o = 0.19 msec, r = 2		t_o = 0.49 msec, r = 5	
	P_r (bar)	I_r (bar-msec)	P_r (bar)	I_r (bar-msec)	P_r (bar)	I_r (bar-msec)
0	3400.00	0	425.00	0	27.2	0
0.1	106.25	79.69	55.97	17.05	10.93	1.76
0.2	13.99	83.95	13.28	19.92	5.06	2.51
0.3	3.32	84.67	4.35	20.71	2.59	2.89
0.4	1.09	84.86	1.75	20.99	1.44	3.08
0.5	0.44	84.93	0.81	21.11	0.85	3.19
0.6	0.20	84.96	0.42	21.17	0.53	3.25
0.7	0.10	84.97	0.23	21.20	0.34	3.30
0.8	0.06	84.98	0.14	21.22	0.23	3.33
0.9	0.03	84.99	0.08	21.23	0.16	3.34
1.0	0.02	84.99	0.05	21.23	0.11	3.36
	$I_r(\infty)$	85.00		21.25		3.40

DISCUSSION

The values selected for the study and the reasons for using the simplified models are as follows: while the assumption of the linear velocity gradient is not precisely right, it has been found to apply very well to many explosive problems, and it was first used by Gurney[1] in his classic study on the initial velocity of fragments from bombs, shells and grenades. It was also checked by Kennedy[2] and found to compare very well for many applications, although it is recognized that it is not precisely accurate for this situation. Typical approximations would indicate that the initial velocity of the product material into a vacuum would be expected to be 6.6 kilometers per second. However, in studies by Lundborg[3] on front and mass velocity at detonation in evacuated chambers, he found that in an actual vacuum the fastest elements leave the surface of the explosive at 20,000 meters per second. Use of V_m of 10,000 meters per second is too slow for the fastest elements, the most highly energetic particles of the ejected material, and yet it overestimates the amount of energy available in the detonation of the explosive.

TABLE 2. Results of Explosive Charge in Case No. 2.

	$r_o = 0.1$ m, $\rho_o = 1{,}700$ kg/m^3, $V_m = 10$ km/sec; $r_m = 1$ m, $V_c = 15$ km/sec, $r_f = 15$ m					
t' (msec)	$R_o = 6.020$ m, $r_m = 1.0$, $\theta_r = 3.82°$		$R_o = 6.082$ m, $r_m = 2$, $\theta_r = 7.66°$		$R_o = 6.578$ m, $r_m = 5$, $\theta_r = 19.47°$	
	P_r (bar)	I_r (bar-msec)	P_r (bar)	I_r (bar-msec)	P_r (bar)	I_r (bar-msec)
0	96.74	0	91.94	0	62.10	0
0.1	44.86	7.08	42.95	6.74	30.60	4.64
0.2	23.05	10.48	22.10	10.00	16.40	6.99
0.3	12.81	12.29	12.30	11.72	9.48	8.28
0.4	7.57	13.29	7.34	12.70	5.78	9.04
0.5	4.70	13.90	4.58	13.30	3.68	9.52
0.6	3.05	14.29	2.97	13.67	2.43	9.82
0.7	2.04	14.54	2.00	13.92	1.66	10.03
0.8	1.41	14.72	1.38	14.09	1.16	10.17
0.9	1.00	14.84	0.98	14.21	0.83	10.27
1.0	0.72	14.92	0.71	14.29	0.61	10.34
1.1	0.54	14.99	0.53	14.35	0.46	10.39
1.2	0.40	15.03	0.40	14.40	0.35	10.43
1.3	0.31	15.07	0.30	14.44	0.27	10.46
1.4	0.24	15.10	0.23	14.46	0.21	10.49
1.5	0.19	15.12	0.18	14.48	0.16	10.51
1.6	0.15	15.13	0.15	14.50	0.13	10.52
1.7	0.12	15.15	0.12	14.51	0.10	10.53
1.8	0.10	15.16	0.09	14.52	0.09	10.54
1.9	0.08	15.17	0.08	14.53	0.07	10.55
2.0	0.06	15.17	0.06	14.54	0.06	10.56
2.1	0.05	15.18	0.05	14.54	--	--

COMPARISON WITH AIR BLAST

The results from Case No. 1, relative velocity zero, can be compared with air blast tables as found in Reference 4. The tables[4] are for one kilogram of explosive in air at 1 bar pressure. Scaling permits comparison of the computed blast parameters in a vacuum to those produced by the same weight of charge at the same distances in air. The results of this comparison are shown in Table 3.

TABLE 3. Comparison of Blast Parameters in Air and in a Vacuum.

	AIR		VACUUM	
Radius, m	Reflected pressure (bars)	Reflected impulse (bar-ms)	Reflected pressure (bars)	Reflected impulse (bar-ms)
1	259	16.51	3,400	85
2	54.9	11.06	425	21.3
5	2.74	2.98	27.2	3.4

r_o = .1 m
W_e = 7.12 kg

NOMENCLATURE

- g Grams
- k Kilo (10^3)
- m Meter
- I_r Reflected impulse
- P_r Reflected pressure
- r Radius to the target (in meters)
- r_o Initial radius of explosive (in meters)
- r_m Miss distance (in meters)
- r_f Fuzing range (in meters)
- R Radius of the gas cloud from blast center
- R_o Initial radius of the gas cloud at intercept
- t Actual time
- t_o Time to reach the target
- t' Time after first encounter
- V_m Peak product velocity (in km/sec)
- V_c Relative closing velocity (antiparallel)
- V_g Gas velocity
- V_r Relative velocity
- x_o Initial distance
- ρ_o Initial density of explosive (in kg/m^3)
- θ Theta (angle in degrees)
- ϕ Phi (angle in degrees)
- ψ Psi (angle in degrees)

10

CONCLUSIONS

In conclusion, the study has shown that there are indeed significant blast-like damage effects available on the detonation of an explosive charge in a vacuum. In a complete study, a more thorough analysis of the processes would be required.

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11